

PATENT SPECIFICATION

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DRAWINGS ATTACHED.

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COMPLETE SPECIFICATION.

Improvements in or relating to the Manufacture of Electrodes.

We, CHEMNR AKTIENGESELLSCHAFT, of Vaduz in the Principality of Liechtenstein, a Body Corporate organized under the laws of the Principality of Liechtenstein, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

5 This invention relates to an electrode for use in an electrolytic process, particularly in the electrolytic production of chlorine and alkali metal in mercury cells and diaphragm cells, the electrolytic production of chlorates, 10 hypochlorites, persulphates, perborates, the oxidation of organic compounds, fuel cells, desalination and purification of water, galvanic processes, and cathodic protection systems. Further the electrode has a long 15 life a low overvoltage and catalytic properties.

15 The invention also relates to processes for making the electrode, and to methods of carrying out electrolyses employing the electrode.

20 Hitherto it has been believed that the best electrode for use as anode in many electrolytic reactions was a solid metallic electrode of a noble metal, such as a metal of the 25 group of the platinum metals. However, by reason of the cost of such metals and certain undesirable technical properties, such as undesirable over-voltage, poor mechanical properties and structural difficulties, ways have 30 been sought to provide electrodes plated with a platinum metal.

35 In recent years there have been developed electrodes on the basis of titanium and coated

with a platinum metal, which have proved to be satisfactory for many uses. It has been found, however, that the electrodes having a titanium base and coated with a platinum metal deteriorate in use at a rate which, although not harmful in many kinds of electrolyses, nevertheless results in the necessity of replacing the electrodes from time to time at considerable expense. 40

In addition, there are other processes, in which the products of the electrolysis should preferably not be contaminated with the material given off by the electrodes. If such a material is present in the products of the electrolysis, it must be removed by a separate treatment. 45

In one aspect, the invention provides an electrode for use in electrolytic processes, comprising a base of a conductive material and a coating on at least part of the surface of the base consisting of a mixed-crystal material comprising (a) the oxide(s) of one or more film-forming metals (as herein defined) in a proportion higher than 50% by weight and (b) one or more non-film-forming conductors (as herein defined), the base, the said oxide(s) and the said conductor(s) being chemically resistant to the electrolyte and to products of the electrolytic process. 50

55 By film-forming metals are understood metals which when connected as an anode in an electrolyte form an oxide coating on their surface which seals off the subjacent metal in such a manner as to bar the passage of current, apart from a minor leakage current, after a short period of time (3 to 5 minutes).

60 By non-film-forming conductors are under-

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stood conductors which when connected as an anode in an electrolyte do not hinder the passage of current, apart from internal resistance, into or out of the electrolyte. By 5 mixed-crystal material is generally understood that the molecular lattices of the oxide of the film-forming metal are intertwined with the molecular lattices of the other material constituting the coating. There are 10 various methods of achieving such a structure, some of which will be described hereinafter in connection with the processes for making the electrode according to the invention, but this is not intended to restrict 15 the scope of the invention.

Preferably, the base is a material selected from aluminum, tantalum, titanium, zirconium, bismuth, tungsten, niobium, or alloys of two or more of these metals. However, 20 other conductive material may be used which will not be affected by the electrolyte and the products formed during the dissociation thereof, it being possible to use metals such as iron, nickel or lead, or alloys thereof, and non-metallic conductive materials 25 such as graphite, in suitable electrolytes.

The other material of the mixture consists of one or more representatives of the 30 non-film-forming conductors. This other material may consist of a mixture of a metal and the oxide of the metal, or of a mixture of two metals, or of a mixture of a metal and an oxide of a different metal, or other combinations of 35 conductors and oxides. Preferably the conductors are gold, silver, platinum, palladium, iridium, ruthenium, osmium, rhodium, iron, nickel, chromium, copper, lead, manganese, and the oxides thereof, graphite, nitrides, 40 carbides, and sulfides.

The coating need not cover the entire surface of the electrode to be immersed in the electrolyte. As a matter of fact, the coating need only cover 2% of the immersed 45 zone, and the electrode will still operate effectively and efficiently.

In a further aspect, the invention provides a process for making an electrode for use in electrolytic processes wherein a mixed-crystal material comprising (a) the oxide(s) 50 of one or more film-forming metals (as herein defined) in a proportion higher than 50% by weight and (b) one or more non-film-forming conductors (as herein defined) is 55 applied to at least part of the surface of a base of conductive material, the base, the said oxide(s) and the said conductor(s) being resistant to the electrolyte and to products of the electrolytic process.

60 There are a number of methods of forming the coating on the base to produce the mixed-crystal material. The most practical one thereof comprises the coprecipitation of an oxide of a film-forming metal with the 65 other material of the mixture constituting

the coating, which coprecipitation may be effected chemically, thermally, electrically, or by a combination of these methods. One method of effecting such a coprecipitation consists in preparing a solution containing materials from which one or more oxides of the film-forming metal can be precipitated, and further materials from which non-film-forming conductors can be precipitated and thereafter treating the solutions in such a manner that the oxide or oxides of the film-forming metal are coprecipitated with the conductors of the non-film-forming type. Among the methods of treating the solution are evaporation of the solvent followed by 70 the thermal formation of the mixed crystals, whereby, when the solution is first applied to the surface of the electrode to be coated, by a treatment such as brushing, immersion, or spraying, the coprecipitated mixture remains behind on the surface of the electrode. Alternatively, the acidity of the solution can be so adjusted that the materials of the mixture are precipitated to form a suspension and then the portion of the electrode to be 75 coated can be immersed in the suspension and an electrophoresis effected to precipitate the materials onto the electrode. Such a method is preferably followed by sintering to promote the adhesion of the deposited 80 mixture to the material of the core of the electrode.

In a preferred embodiment of the invention the process comprises preparing a solution containing a solvent, a soluble compound(s) of the one or more film-forming metals from which the oxide(s) is/are precipitated on heating, and a soluble compound(s) of the one or more non-film-forming conductors from which the non-film- 85 forming conductor is precipitated on heating, applying the solution to at least part of the surface of the base and heating the base 90 to deposit the said mixed-crystal material 95 thereon.

Generally speaking, the formation of the mixed crystal material can be effected thermally by heating the base in the air, but in some cases this can be beneficially affected by conducting the heat treatment under sub- 100 atmospheric or super-atmospheric pressure. The heating may be effected by resistance 105 heating or high-frequency heating.

110 Preferably, the heating is effected at a temperature of from 200 to 1,200°C.

A different method of making the electrode consists in the use of the so-called vacuum-sputtering techniques, in which the base is placed in a vacuum and connected as a cathode, and anodes of one or more 115 film-forming metals, are placed in the vacuum together with an anode of an electrolytic non-film-forming metal or an oxide thereof, or anodes of electrolytic non-film-forming metals or oxides thereof, and the 120

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sputtering current is conducted through the anodes and the cathode so that the electrolytic film-forming metal oxide or oxides are sputtered onto the cathode together with the electrolytic non-film-forming metal or metals or oxide or oxides thereof.

In another method of making the electrode, the mixed-crystal material is prepared by co-precipitation of the oxide(s) of the one or more film-forming metals with the one or more non-film-forming conductors, and is then applied to the base by means of hammering or rolling.

In another method of making the electrode, the mixed-crystal material is prepared by co-precipitation of the oxide(s) of the one or more film-forming metals with the one or more non-film-forming conductor(s), and is then applied to the base by means of a plasma burner.

In one embodiment of the method, the solvent is an organic solvent and the soluble compounds of the film-forming metals are selected from organic titanates (preferably, butyl titanate monomer, butyl titanate polymer, or tetra-2-ethyl-hexyl titanate), organic tantalates (preferably, pentaethyl tantalate), organic niobates (preferably, niobium pentaethylate), and organic zirconates (preferably, zirconium acetyl acetoneate).

The solution may further contain a free acid, such as hydrochloric acid or hydrobromic acid.

The solution may further contain iodine. Still another method of making the electrode according to the invention consists in the use of an electrolysis. The base of the electrode is immersed in an electrolyte consisting of a solution of salts or other compounds of one or more film-forming metals, from which solution the oxide or the oxides will co-precipitate onto the electrode when the solution is subjected to electrolysis. The solution also contains a soluble compound of a non-film-forming metal or metals or of an oxide or oxides of such metals which will also co-precipitate during the electrolysis. The electrolysis can be effected either by passing an alternating current through the electrode, or by using the electrode as an anode and conducting a direct current through it.

When the mixtures are applied electrolytically, this is best effected under anodic conditions, and preferably so that one or more hydroxides of the metals are deposited on the base, such hydroxides being subsequently sealed by boiling in demineralized water or by heating.

Preferably, the base is pretreated in order to clean the surface thereof before the coating is applied. Such pretreatment may comprise degreasing the surface of the base, roughening the surface of the base, or cleaning by ultrasonic vibrations.

In a still further aspect, the invention provides any electrolytic process using an above-mentioned electrode.

The manner in which the electrode according to the invention is used will be readily apparent to those skilled in the art. For most uses, the electrode is placed as an anode in an electrolysis apparatus, and the electrolysis is carried out in the conventional manner and under conventional conditions, the product or products of the electrolysis being yielded in the conventional manner, or the purified electrolyte being recovered, as desired. Examples of processes in which the electrode is thus used are the electrolysis of brine in mercury cells or diaphragm cells for the production of chlorine and alkali metal, the electrolytic production of chlorates, hydrochlorites, persulphates, and perborates, the electrolytic oxidation of organic compounds, such as liquid or gaseous hydrocarbons, for example, propylene or ethylene, the electrolytic deposition of metals, desalination of water, sterilization of water, and fuel cells. The electrode is also excellently suitable for use as an anode in cathode protection systems and as a cathode in bi-polar cells.

The invention will now be described in greater detail with reference to an embodiment shown by way of example only in the accompanying drawings, in which:

Fig. 1 is a cross-section of the electrode according to the invention; and

Fig. 2 is a graph in which the performance of prior electrodes is compared with that of an electrode according to the invention.

Referring to the drawings, the electrode according to the invention consists of a base or core 10 having a coating 11 thereon, 105 which two parts consist of materials which will be described more fully hereinafter.

The electrode is shown as having a simple rectangular shape, but it will be understood that the electrode is not limited to such a configuration, but may have any configuration suitable for the electrolysis apparatus in which the electrode is to be used. Furthermore, there is shown a simple cavity 12 at the top for connecting the current conductor thereto, but this feature does not constitute part of the invention and may be changed as desired.

As explained above, the provision of the mixed-crystal coating is the particular feature accounting for the outstanding performance of the electrode according to the invention. The importance of the restriction that the coating must behave as a mixed-crystal material rather than as a mere mixture of the two oxides can be shown by means of several examples. Iron oxide itself is highly sensitive to hydrochloric acid at room temperature, and so are several titanium oxides. It has been found, however, that 130

when a co-precipitated mixture of iron oxide and titanium oxide is applied to a basis of conductive material it is only affected by hydrochloric acid at room temperature to a very small extent. Similarly, ruthenium oxide coated on a titanium base, connected as an anode in an alkali metal chloride electrolysis, which anode is contacted with the amalgam formed in a mercury cell, loses a part of its thickness after a prolonged period of electrolysis, because the reductive properties of the amalgam convert the ruthenium oxide into metallic ruthenium, and the metallic ruthenium is readily dissolved in the amalgam from the surface of the titanium and is not resistant to the electrolyte. Co-precipitated mixed oxides of titanium oxide and ruthenium oxide, however, which are in contact with such an amalgam are resistant to the amalgam because these oxides when in mixed-crystal form are not reduced and so do not dissolve in the amalgam or in the generated chlorine.

It should be noted that the mixed crystals which are applied to the electrodes according to the present invention are quite different from those obtained, for example, by mere heating in the air of the solid noble metals, or when these are superimposed in discontinuous layers in finely-divided condition on other metals. Generally speaking, it may be said that the oxidation of the solid metals by mere heating is very difficult, and

that, although finely-divided noble metals may be oxidized, the adhesion of such oxides to the substrate is often very poor. Electrolytic oxidation is also very difficult, and in addition layers produced in this manner also show poor adhesion, so that a mechanically weak electrode is formed. The problem of rendering the oxides of the noble metals and other metals in finely-divided condition adhesive and at the same time resistant is now solved by virtue of the co-precipitation of the non-film-forming conductors with the oxides of the film-forming metals. It is surprising, for example, that palladium oxide, platinum oxide, and ruthenium oxide are then fully resistant. Therefore platinum, applied to a metallic base, when heated in the air or used as an anode in the electrolysis of alkali metal chloride, definitely does not acquire the condition required according to the present invention, that is to say, that an adhering mixture is co-precipitated thereon.

The following Table A clearly indicates the difference between the co-precipitated oxides and the other oxides which may be formed thermally or electrolytically when, for example, an electrode consisting of a base of metallic titanium and a coating of a platinum metal is oxidized in the air or used to electrolyse a dilute solution of an alkali metal chloride or dilute hydrochloric acid.

Chemical and electrolytic properties of singular oxides as compared with the mixed crystal material of electrode according to the invention

Thermal oxidation in air at 500°C of Pt/Pd/Ag/Fe/Ru in finely-divided condition on titanium base			
70	Formation of oxide	...	...
	Adhesion to base metal	...	...
	Resistance to 0.2% by weight sodium amalgam	...	...
75	Overvoltage in chlorine electrolysis at 8000 amps/m ²	...	...
	Loss of oxides per ton of chlorine at 8000 amps/m ²	...	...
80	Chemical resistance to aqua regia without current	...	...
	Resistance to reduction	...	...
	Catalytic properties in the oxidation of organic compounds	...	...
	Mechanical strength	...	...
			B / B / B / B / G
			B / B / B / B / B
			B / B / B / B / B
			B / B / — / — / B
			M / M / — / — / M
			B / B / — / — / B
			B / B / B / B / B
			B / B / B / B / B
			B / B / B / B / B

Electrolytic oxidation in dilute sulphuric acid of Pt/Pd/Ag/Fe/Ru in finely-divided state on titanium base

5	Formation of oxide	...	...	N / B / B / --/ G
	Adhesion to base metal	...	...	--/ --/ B / --/ B
	Resistance to 0.2% by weight sodium amalgam	...	...	--/ B / B / --/ B
10	Oxervoltage in chlorine electrolysis at 8000 amps/m ²	...	...	--/ B / --/ --/ G (for a short time)
	Loss of oxides per ton of chlorine at 8000 amps/m ²	...	...	--/ M / --/ --/ M
	Chemical resistance to aqua regia without current	...	...	--/ B / --/ --/ B
15	Resistance to reduction	...	...	--/ B / --/ --/ B
	Catalytic properties in the oxidation of organic compounds	...	...	--/ B / B / B / B
	Mechanical strength	...	...	--/ B / B / B / B

20				Co-precipitated oxides of Ru/Ti, Pt/Zr, Pd/Ta, Ag/Ti, Fe/Ti, and Pt/Ti in finely-divided state on titanium base
	Formation of oxide	...	...	E / E / E / E / E
	Adhesion to base metal	...	...	E / E / E / E / E
25	Resistance to 0.2% by weight sodium amalgam	...	...	E / E / E / --/ E / E
	Oxervoltage in chlorine electrolysis at 8000 amps/m ²	...	...	E / E / E / --/ --/ E
30	Loss of oxides per ton of chlorine at 8000 amps/m ²	...	...	L / L / L / --/ --/ L
	Chemical resistance to aqua regia without current	...	...	E / E / E / --/ --/ E
	Resistance to reduction	...	...	E / E / E / --/ --/ E
35	Catalytic properties in the oxidation of organic compounds	...	...	E / E / E / --/ --/ E
	Mechanical strength	...	...	E / E / E / --/ --/ E

Key: E — excellent

B — bad

G — good

40 N — practically no oxide formed
M — much
L — very little

In a test designed to show quantitatively the improvement obtained by electrodes according to the invention as compared with other electrodes in contact with 0.2% by weight sodium amalgam under a constant electric load of 10.000 Amp/m² during electrolysis and of 80.000 Amp/m² during short-circuiting with the amalgam, a number of titanium bases were respectively coated with (1) metallic ruthenium, (2) a mixture of platinum and iridium (70/30 weight/weight), (3) a co-precipitated mixture of ruthenium oxide and titanium oxide (90 mol % / 10 mol %), and (4) a co-precipitated mixture of ruthenium oxide and titanium oxide (30 mol % / 70 mol %). All these materials were present in a thickness of 10 g/m². The electrodes were introduced into a brine test cell containing 0.2% by weight sodium amalgam, which quantity was kept constant, the brine in the cell having a concentration of 28% by weight and a temperature of 80°C, the applied current density being 10.000 Amp/m². These conditions are the same as may be the case in a large-scale cell. Fig. 2 shows the overvoltage in millivolts plotted against the time. It will be seen that, whereas the overvoltage of the first, second and third electrodes increased relatively rapidly owing to the contact with the amalgam, the overvoltage of the electrode according to the invention, i.e. containing more than 50% by weight titanium oxide, only increased gradually during a long period of time.

The invention is illustrated, but not limited, by the following examples in which all percentages given are by weight.

EXAMPLE I

40 6.2 cc butyl alcohol
0.4 cc HCl 36%
3 cc butyl titanate
1 g RuCl₃

The solution was several times brushed on to a cleaned titanium plate (grain size 45 titanium 0.04—0.06 mm; ASTM 6) of 10×10 cm and a thickness of 1 mm, the plate being first pickled in hot aqueous oxalic acid, subjected to ultrasonic vibration in water, and dried. The coated plate thus 50 treated was heated in the air at a temperature of 300—500°C for 1—5 minutes.

The resulting electrode had a coating of ruthenium oxide coprecipitated with titanium oxide, the titanium oxide being present in a proportion of 70 mol %, the balance being RuO₂.

The resulting electrode was placed in a hydrochloric acid cell as an anode, the cathode being a silver plated titanium electrode. Flowing hydrochloric acid of 25% was electrolyzed at 70°C and 2500 Amp/m² for practically one year with excellent re-

sults and with losses of less than 0.1 g ruthenium per ton of chlorine.

The resulting electrode was placed in a brine electrolysis cell as an anode, the cathode being mercury and the brine having a concentration of 28% a pH of about 2.5, and a temperature of 80°C. The spacing between anode and cathode was less than 2.5 mm. When a current density of 10.000 Amp/m² was applied, the anode had an extremely low overvoltage of about 80 millivolts, measured against a calomel reference electrode, and this was maintained for a long period of time, even after various short-circuitings with the amalgam.

The resulting electrode was placed in a brine diaphragm cell as an anode, the cathode being iron, and the brine having a concentration of 28%, a pH of about 3.5, and a temperature of 80°C. At a current density of 1000 Amp/m², the anode had an extremely low overvoltage of 60 mVolts and maintained this for a long period of time. The losses of metallic ruthenium were less than 0.15 g per ton of produced chlorine, in the mercury cell and less than 0.1 g of produced chlorine in the diaphragm cell.

The resulting electrode was also used in a cathodic protection system as anode for the protection of a ship. The electric design was a conventional system well-known to those skilled in the art. The anode showed good electrical and mechanical properties.

The resulting electrode was extremely suitable for the oxidation of unsaturated organic compounds, such as ethylene and propylene, as well as for the preparation of chlorates.

The resulting electrode was also suitable for electrodialysis, because it readily admits of pole changing.

The resulting electrode was also used in a galvanic metal deposition process, in which 105 gold was deposited on copper from a bath having the following composition: gold chloride 30 g/l, nitric acid (specific gravity 1.19) 25 cc/l, sodium chloride 12 g/l, sulphuric acid (specific gravity 1.025) 13 g/l (+organic brighteners). By means of this bath, at 70°C, and a current density of 8—10 Amp/m², an excellent plating on the cathode was obtained, the overvoltage at the anode being such that no damage was done 115 to the bath.

EXAMPLE II

80 cc TiCl₃-solution in H₂O
(25% TiO₂)
1 g RuCl₃

This mixture was absorbed in a graphite anode at a sub-atmospheric pressure this anode being previously subjected to ultrasonic vibrations for 10 minutes. Sub-

sequently the anode was heated in a stream of air for $\frac{1}{2}$ hour at a temperature of 300—800°C. This treatment was repeated four times. The resulting electrode had a coating of ruthenium oxide, co-precipitated with titanium oxide, the titanium oxide being present in a proportion of 98.4 mol % TiO_2 , there being 1.6 mol % RuO_2 .

An untreated graphite anode was placed in an alkali metal chloride cell containing 28% brine of a pH of about 2.5 and a temperature of 80°C as the electrolyte and a mercury cathode. The distance between the anode and the cathode was less than 2.5 mm. A current of a density of 8.000 Amp/m² was passed through the cell. The anode first had an overvoltage of about 400 mV, which decreased to 360 and after a considerable time increased to 450 mV. Furthermore, the untreated anode showed marked erosion after a short while, and as a result the brine solution became black with the graphite released. In addition to the contamination of the bath liquid, the loose graphite caused stray currents, resulting in loss of efficiency and discharge of the amalgam. Furthermore, the spacing between the anode and the cathode required adjustment at regular intervals, because this spacing changed as a result of the erosion of the anode, resulting in loss of energy in the electrolyte.

The electrode according to this example, placed in the same electrolyte under the same conditions, had an overvoltage of only 70 mV, which overvoltage remained constant during a considerable time. Moreover, the bath remained clear and the anode showed no erosion. Accordingly, not only was the electrolyte not contaminated, but the electrodes did not require adjustment.

The electrode according to the invention was also used as an anode in a cathode protection system of a conventional type and operated excellently.

45 EXAMPLE III

A tantalum plate was cleansed well and mechanically roughened, and a coating mixture was prepared as follows:

50 18 cc isopropyl alcohol
1 g iridium chloride
2 g platinum chloride
4 g isopropyl titanate
3 cc anise-oil (reducing agent)

55 Lavender oil or linalool may be used instead of the anise-oil.

The mixture was brushed onto the tantalum plate several times, and the coated base was subsequently heated at a temperature of 600°C for several minutes. The resulting electrode had a coating of iridium and platinum, co-precipitated with titanium oxide, the titanium oxide being present in a

proportion of 65.8 mol % in addition to 12.65 mol % iridium oxide and 21.55 mol % platinum oxide.

This electrode operated excellently in electrolytic processes for the preparation of chlorine, oxygen, oxidation of organic compounds, and in galvanic baths.

EXAMPLE IV

A zirconium plate was degreased and a coating mixture was prepared as follows:

10 cc water
1 g gold chloride
3 cc 25% titanium chloride solution
0.1 cc wetting agent

This mixture was brushed onto the degreased plate and the plate was heated in the air at a temperature of 200—300°C and at a superatmospheric pressure. This treatment was repeated 8 times.

The resulting electrode had a coating of gold oxide coprecipitated with titanium oxide, the titanium oxide being present in a proportion of 74 mol % and the gold oxide in a proportion of 26 mol %.

This electrode operated excellently in dilute sulphuric acid solutions.

EXAMPLE V

A titanium rod was degreased and then pickled for 8 hours in a 10% oxalic acid solution at 90°C. The rod was subsequently brushed with the following mixture:

30 cc $TiCl_3$ solution in water
3 g anhydrous ferric chloride
1 g ferrous chloride

The resulting rod was subsequently heated in a space filled with a mixture of steam and air at a temperature of 450—600°C for 100 1—2 hours.

The resulting rod was connected in a cathodic protection system. The electrode operated excellently in alkaline solutions at current densities up to 1,000 Amp/m².

EXAMPLE VI

6.2 cc butyl alcohol
0.4 cc hydrochloric acid 36%
1 g zirconium acetyl acetonate
1 g iridium chloride, dry

The solution was applied to a zirconium base as described in Example IV, the base being previously degreased, pickled, and subjected to ultrasonic vibrations. After the application of the solution the base was heated at 500—700°C for several minutes by clamping the base between two copper plates heated throughout their surface. This

resulted in a highly uniform heating of the overall surface, which was highly beneficial to the quality of the anode. The treatment was repeated several times. The ratio of 5 zirconium oxide to iridium oxide in the mixture had been so selected that more than 50 mol % of zirconium oxide was present in it. The anode thus made was excellently suitable for all kinds of electrolytic processes, particularly for the electrolysis of 10 sulfuric acid solutions and solutions of sulfates.

EXAMPLE VII

15 9 cc butyl alcohol
 0.4 cc hydrochloric acid 36%
 1 g palladium chloride
 3 cc pentaethyl tantalate.

A tantalum base was dipped into the above solution and after drying heated at 20 500—800°C to deposit a mixture thereon of 62 mol % tantalum oxide and 38 mol % palladium oxide. This treatment was repeated six times. The tantalum base was a thin tube which after the completion of the 25 coating was provided with a copper rod acting as a current conductor, because the tantalum tube comprised insufficient metal for it to be able to transport current without undue losses. In order to ensure proper contact between the tantalum tube and the copper rod, the inner surface of the tantalum tube was electrolytically copper-plated. Intimate contact between the copper rod and the copper inner coating was obtained by 30 applying molten tin therebetween and allowing the tin to solidify.

The anode made in this manner was excellently suitable for cathodic protection purposes with an applied voltage of higher 40 than 20 volts, and also is an excellent anode for the preparation of hypochlorites.

EXAMPLE VIII

45 6.2 cc butyl alcohol
 0.4 cc hydrochloric acid 36%
 1 g ruthenium chloride
 3 cc niobium pentaethylate.

A niobium base was degreased and connected as an anode in an electrolyte to form an oxide coating thereon. This coating was 50 subsequently rinsed thoroughly and dried. The anode with the oxide coating thereon was dipped into the above solution and subjected to high-frequency heating at 600°C at a subatmospheric pressure of 100 mm Hg 55 to convert the reactants to the desired mixture. This treatment was repeated several times until the desired mixture was present on the niobium in a thickness of 2 microns. The anode thus made was excellently suit-

able for all kinds of electrolytic processes, such as for the preparation of chlorine, chlorates, and hypochlorites, for the sterilization of swimming-pools. 60

EXAMPLE IX

A titanium plate was degreased and 65 pickled and subsequently an oxide coating of about 1 mm thickness was applied to it by means of electrolysis.

A mixture of:

70 10 cc butyl alcohol
 1 g ruthenium oxide powder
 3 cc butyl titanate

was painted onto it and converted into the desired mixture at a temperature of 300—600°C. This treatment was repeated so 75 many times that 10 g of the desired mixture was present on the surface of the titanium plate.

The anode made in this manner was excellently suitable for the electrolytic preparation of chlorine, and chlorine compounds, and for cathodic protection purposes. 80

The electrolytically formed oxide on the titanium highly promotes the adhesion of the mixture formed. 85

EXAMPLE X

A niobium expanded metal plate was pre-treated in known manner and subsequently brushed with a solution of:

90 10 cc water
 1 g ruthenium chloride
 $\frac{1}{2}$ cc hydrochloric acid (35%)
 2 g titanium hydroxide.

The plate was subsequently heated at 400—700°C for several minutes until the 95 desired mixture formed. This treatment was repeated until 6 g of the mixture was present on the surface.

This anode was excellently suitable for the electrolysis of alkaline solutions. 100

EXAMPLE XI

An aluminum plate was degreased and pickled in a conventional manner. There was then prepared a mixture of:

105 10 cc isopropyl alcohol
 1 g aluminum bromide
 1 g platinum chloride
 0.01 g iodine.

The aluminum plate was dipped into this mixture and heated at 400°C to form the 110 required mixture, the latter consisting of 62.2 mol % Al_2O_3 and 37.8 mol % PtO_2 .

This treatment was repeated several times, the mixture being applied to the plate either by dipping or painting. 115

The electrode thus made is excellently suitable for the electrolysis of boric acid compounds.

EXAMPLE XII

5 The following mixture was prepared:

10 cc butyl alcohol
6 cc butyl titanate
2 g graphite (can be replaced by
10 titanium nitride or
tantalum carbide or
rhenium sulfide)

This mixture was painted onto a titanium base and heated at a temperature of 400—700°C, which treatment was repeated a number of times.

15 An anode thus coated with graphite and titanium oxide is particularly suitable for electrolyses in which a low current density is desirable, for example, cathodic protection of subterranean objects.

20 Anodes in which the coating contains in addition to titanium oxide a nitride, carbide, or sulfide are resistant to high current densities in various electrolytes.

25 EXAMPLE XIII

2 g titanium chelate
1 g ruthenium chelate

These two chelates were intimately admixed in the dry state and subsequently placed on the bottom of a vessel which can be closed and heated. A degreased, pickled titanium rod, covered as to 98% with a heat-resistant silicon lacquer layer, was introduced into the vessel. By heating the chelates, a mixture of titanium oxide and ruthenium oxide was evaporated onto the 2% of exposed titanium, and the required crystal form was obtained by sintering. A small quantity of hydrochloric acid vapour in the 30 vessel promotes the adhesion of the mixed oxide. Subsequently the lacquer layer was removed. The resulting electrode has an active surface area of about 2%.

35 This electrode is excellently suitable as an anode for the sterilization of water in swimming-pools or for the electrolysis of two layers of liquid, in which a local electrolysis of either of the liquids is desired.

40 Naturally, partly coated anodes may also be made in different manners from that described in this example.

EXAMPLE XIV

55 10 cc butyl alcohol
2 cc butyl titanate
1 cc pentaethyl tantalate
1 cc pentaethyl niobate
1 g ruthenium chloride, bromide, or iodide
0.1 g hydrogen chloride

A zirconium base was degreased and pickled in known manner. The above mixture was painted onto the base and converted by heating at 400—700°C in air. This treatment was repeated until 40 g/m² of the desired mixture was present on the surface. The mixed crystal consisted of the oxides of titanium, tantalum, and niobium as oxides of film-forming metals and ruthenium oxide as non-film-forming conductor.

60 In addition, some zirconium oxide had formed thermally on the boundary surface of the mixture and the zirconium rod. The quantity of oxides of film-forming metals was more than 50 mol %, calculated on the overall mixture.

65 Such an anode is particularly suitable for all kinds of electrolyses, such as of sulphuric acid compounds, for the purification of water, and for the preparation of chlorates.

EXAMPLE XV

70 A titanium plate was degreased, pickled, and subjected to ultra-sonorous vibrations. Subsequently the plate was placed as an electrode in a stirred emulsion consisting of:

75 100 cc water
100 cc acetone
5 g extremely finely-divided mixture of co-precipitated platinum oxide (3 g) and titanium oxide (2 g)
90 1 g emulsifying agent

The second electrode was constituted by a platinum plate. By applying an electric voltage of 10—100 volts, the titanium was electrophoretically coated with a mixed oxide from the emulsion. After being removed from the bath, the titanium with the coating deposited thereon was carefully dried and subsequently heated at 400°C for several minutes. Thereafter the electrophoretically deposited layer had an excellent adhesion to the titanium, and the anode thus made is suitable for various kinds of electrolyses.

95 The adhesion is highly promoted by pre-oxidizing the titanium base by means of heat or electrolytically, and then applying the mixed oxide by electrophoresis.

100 This example was repeated using a mixture of co-precipitated platinum oxide, 110 titanium oxide, and manganese dioxide. There is thus obtained an anode having a high overvoltage and catalytic properties.

EXAMPLE XVI

115 Two titanium rods were degreased and pickled and subsequently placed in a galvanic bath having the following composition:

100 cc ethanol
100 cc water
1 g ruthenium chloride
10 g titanium chloride

5 and subsequently connected to a source of alternating current of 13 volts and a current density of 15 Amp/m², temperature 20—30°C, for a period of time of about 20 minutes.

10 After about 20 minutes both rods were coated with a mixture of titanium oxide and ruthenium oxide, and adhesion of which was still further improved by heating at 400°C for 5 minutes.

15 The anode thus made is excellently suitable for use in various electrolyses effected at low current densities.

EXAMPLE XVII

20 A titanium rod was degreased and subsequently electrolytically provided with an oxide coating of a thickness of about 5 microns. The rod thus treated was placed as an anode in a bath (80°C), containing:

25 100 cc water
5 g yellow lead oxide
5 g sodium hydroxide
3 cc hydrogen peroxide
10 cc titanium chloride solution (25% TiO₂)

30 This bath is regularly insufflated with air. The treated titanium rod was connected as anode, an iron plate being used as the cathode. The voltage differential between the anode and the cathode was about 2—3 volts, and the current density was about 5 Amp/m².

35 After about an half hour, the titanium anode was coated with a mixture of titanium oxide and lead oxide, the properties of which could be considerably improved by heating at 200—600°C.

40 An anode thus treated is suitable for use in electrolyses in which no high-current densities are necessary.

45 EXAMPLE XVIII

Titanium expanded metal was degreased and pickled, and then painted with the following mixture:

50 10 cc butyl alcohol
1 g ruthenium chloride
3 cc zirconium acetyl acetone.

55 Subsequently the product was heated at 400—700°C. This treatment was repeated until the mixture on the titanium had a thickness of $\frac{1}{2}$ micron.

An electrode thus made is excellently suitable for the electrolysis of solutions of sulphuric acid compounds, the resistance of

the titanium to sulphuric acid being greatly increased by virtue of the mixed surface coating containing zirconium oxide. 60

EXAMPLE XIX

A tantalum wire was degreased and pickled, and then dipped into a mixture of

10 cc butyl alcohol
3 cc butyl titanate
1 g iridium chloride 65

The wire was then heated at a temperature of 500—700°C, and the treatment was repeated until at least 2.5 g of the mixture per m² was present on the surface of the tantalum. 70

A tantalum wire thus treated is excellently suitable for use as an anode for the cathodic protection of ships. 75

EXAMPLE XX

A titanium plate was degreased, pickled, subjected to ultrasonic vibrations and then rinsed thoroughly and dried. This plate was subsequently connected as a cathode in an apparatus in which metals can be vacuum deposited. As anodes, a bar of platinum and bars of titanium were connected, the ambient atmosphere containing so much oxygen that the anodic materials were deposited on the titanium cathode as oxides (a detailed description of this apparatus is contained in the book by L. Holland, Vacuum Deposition, 1963, pages 454—458). 80

After several minutes a mixture of titanium oxide and platinum oxide had deposited on the titanium, and the titanium thus treated is excellently suitable for the electrolysis of aqueous electrolytes. 85

90 EXAMPLE XXI
Niobium was degreased and subsequently provided with an oxide coating of a thickness of at least 1 micron. This can be effected either electrolytically or thermally. Subsequently a paste was prepared of: 100

10 cc ethanol
1 g ruthenium oxide
4 g titanium oxide.

95 This mixture was intimately admixed, heated, sintered, comminuted, and again mixed with 10 cc ethanol. The resulting paste was applied to the oxidized niobium in a thin layer, and subsequently heated at a temperature of 450—700°C. This treatment was repeated until at least 10 g of the desired mixture per m² was present on the surface. 105

A niobium plate thus treated is excellently suitable for the electrolysis of electrolytes. 110

EXAMPLE XXII

A soft-quality titanium rod was degreased and then a mixture of more than 50 mol % titanium oxide and less than 50 mol % palladium oxide was rolled into it under pressure. Alternatively, this may be effected by hammering.

The oxides were prepared by dissolving water-soluble salts of the metals in water in the required proportions, from which solution they were precipitated with lye, washed, and carefully dried. In this manner a very fine mixed oxide was obtained, which could be hammered or rolled into the titanium without undue trouble. Other conventional methods of preparing these mixed oxides can naturally be used as well.

Furthermore, other metals than titanium can naturally be treated in this manner.

20 EXAMPLE XXIII

6.2 cc butyl alcohol
0.4 cc water
3 cc butyl titanate
1 g ruthenium chloride.

25 The above solution was painted onto a titanium base and heated as described in Example I.

An anode thus made is particularly suitable for the electrolysis of zinc sulphate or copper sulphate solutions, which may be contaminated with nitrate or chloride, for the manufacture of the metals concerned.

EXAMPLE XXIV

35 A zirconium plate was degreased and subsequently provided with the desired mixture of oxides by means of a so-called plasma burner.

40 There is thus obtained a very thin, but excellently adhering layer, and a zirconium plate provided with such a coating is excellently suitable for all kinds of electrolyses.

WHAT WE CLAIM IS:—

45 1. An electrode for use in electrolytic processes, comprising a base of a conductive material and a coating on at least part of the surface of the base consisting of a mixed-crystal material comprising (a) the oxide(s) of one or more film-forming metals (as herein defined) in a proportion higher than 50% by weight and (b) one or more non-film-forming conductor(s) (as herein defined), the base, the said oxide(s) and the said conductor(s) being chemically resistant to the electrolyte and to products of the electrolytic process.

50 2. An electrode as claimed in claim 1, wherein the one or more film-forming metals are selected from aluminium, tantalum, titanium, zirconium, niobium, bismuth and tungsten.

3. An electrode as claimed in claim 1 or 2, wherein the non-film-forming conductors are palladium, platinum, rhodium, iridium, ruthenium, osmium, silver, gold, iron, nickel, chromium, lead, copper, manganese, oxides thereof, graphite, nitrides, carbides, and sulfides. 65

4. An electrode as claimed in claim 1, 2 or 3, wherein the base is a material selected from aluminium, tantalum, titanium, zirconium, bismuth, tungsten, niobium, iron, nickel, lead, alloys thereof, and graphite. 70

5. An electrode as claimed in any one of claims 1 to 4 wherein the coating is a mixed-crystal material consisting of 70 mol % of titanium oxide and 30 mol % of ruthenium oxide. 75

6. An electrode as claimed in any one of claims 1 to 4, wherein the coating is a mixed-crystal material consisting of 62 mol % tantalum oxide and 38 mol % palladium oxide. 80

7. An electrode as claimed in any one of claims 1 to 6, wherein the coating covers at least 2% of that surface of the electrode intended to be placed in electrolyte. 85

8. An electrode substantially as herein described with reference to any one of the Examples given.

9. A process for making an electrode for use in electrolytic processes wherein a mixed-crystal material comprising (a) the oxide(s) of one or more film-forming metals (as herein defined) in a proportion higher than 50% by weight and (b) one or more non-film-forming conductors (as herein defined) is applied to at least part of the surface of a base of conductive material, the base, the said oxide(s) and the said conductor(s) being resistant to the electrolyte 90 and to products of the electrolytic process. 95

10. A process as claimed in claim 9, wherein the one or more film-forming metals are selected from aluminium, tantalum, titanium, zirconium, niobium, bismuth and tungsten. 100

11. A process as claimed in claim 9 or 10, wherein the non-film-forming conductors are palladium, platinum, rhodium, iridium, ruthenium, osmium, silver, gold, 110 iron, nickel, chromium, lead, copper, manganese, oxides thereof, graphite, nitrides, carbides and sulfides.

12. A process as claimed in claim 9, 10 or 11, wherein the base is a material selected from aluminium, tantalum, titanium, zirconium, bismuth, tungsten, niobium, iron, nickel, lead, alloys thereof, and graphite. 115

13. A process as claimed in any one of claims 9 to 12, wherein the coating covers at least 2% of that surface of the electrode intended to be placed in electrolyte. 120

14. A process as claimed in any one of claims 9 to 13, wherein the base is pre-

treated in order to clean the surface thereof before the coating is applied.

15. A process as claimed in claim 14, wherein the pre-treatment comprises de-
5 greasing the surface of the base.

16. A process as claimed in claim 14 or 15, wherein the pre-treatment comprises roughening the surface of the base.

17. A process as claimed in claim 14, 10 wherein the pre-treatment comprises cleaning by ultrasonic vibrations.

18. A process as claimed in any one of claims 9 to 17, comprising preparing a solution containing a solvent, a soluble com-
15 pound(s) of the one or more film-forming metals from which the oxide(s) is/are pre-
cipitated on heating, and a soluble com-
pound(s) of the one or more non-film-form-
ing conductors from which the non-film-
20 forming conductor is precipitated on heat-
ing, applying the solution to at least part of
the surface of the base and heating the base
to deposit the said mixed-crystal material
thereon.

25. 19. A process as claimed in claim 18,
wherein the heating is effected at a tem-
perature of from 200 to 1,200°C.

20. A process as claimed in any one of claims 9 to 17, comprising preparing a solution containing a solvent, a soluble com-
30 pound(s) of the one or more film-forming metals from which the oxide(s) is/are de-
posited on electrolysis of the solution, and
a soluble compound of one or more non-
35 film-forming conductors from which the
non-film-forming conductor(s) is/are de-
posited on electrolysis of the solution, plac-
ing in the solution the base of conductive
40 material and passing an alternating current
through the base and the solution.

21. A process as claimed in claim 20,
wherein in place of an alternating current,
a direct current is used, and the base is the
anode.

45. 22. A process as claimed in any one of claims 9 to 17, wherein a solution is pre-
pared containing a solvent and a soluble com-
pound(s) of the one or more film-forming metals from which the oxide(s) can be
50 precipitated to form a suspension, and a
soluble compound(s) of the one or more non-film-forming conductors from which the
non-film-forming conductor can be pre-
cipitated to form a suspension, coprecipitat-
ing a suspension of the said oxide(s) and
55 non-film-forming conductor(s), placing at
least part of the base in the suspension and
carrying out an electrophoresis to deposit
the mixed-crystal material on the base.

60. 23. A process as claimed in claim 22,
wherein the coated electrode is sintered.

24. A process as claimed in any one of claims 9 to 17, wherein the mixed-crystal
65 material is prepared by co-precipitation of
the oxide(s) of the one or more film-forming

metals with the one or more non-film-forming conductors, and is then applied to the base by means of hammering or rolling.

25. A process as claimed in any one of claims 9 to 17, wherein the mixed-crystal material is prepared by co-precipitation of the oxide(s) of the one or more film-forming metals with the one or more non-film-forming conductor(s), and is then applied to the base by means of a plasma burner.

26. A process as claimed in any one of claims 18 to 23, wherein the solvent is an organic solvent and the soluble compounds of the film-forming metals are selected from organic titanates, organic tantalates, organic niobates, and organic zirconates.

27. A process as claimed in claim 26,
wherein the organic titanate is butyl titanate
monomer, butyl titanate polymer or tetra-2-
ethyl-hexyl titanate.

28. A process as claimed in claim 26,
wherein the organic tantalate is pentaethyl
tantalate.

29. A process as claimed in claim 26,
wherein the organic niobate is niobium
pentaethylate.

30. A process as claimed in claim 26,
wherein the organic zirconate is zirconium
acetyl acetonate.

31. A process as claimed in any one of claims 18 to 30, wherein the solvent is an organic solvent and the solution further contains a free acid.

32. A process as claimed in claim 31,
wherein the acid is hydrochloric acid.

33. A process as claimed in claim 31,
wherein the acid is hydrobromic acid.

34. A process as claimed in any one of claims 18 to 33, wherein the solution further contains iodine.

35. A process as claimed in any one of claims 18 to 23, wherein the solution is an aqueous solution and the soluble compounds of the film-forming metals are the halides.

36. A process as claimed in any one of claims 18 to 35, wherein the coated electrode is placed in an atmosphere containing oxygen and heated therein.

37. A process as claimed in any one of claims 18 to 25, wherein the at least one non-film-forming conductor is present in the form of a suspension in the solution before precipitation.

38. A process as claimed in any one of claims 18 to 25 or claim 37, wherein the oxide of a film-forming metal is present in the form of a suspension in the solution before precipitation.

39. A process as claimed in any one of claims 9 to 17, wherein the base of conductive material is placed in a vacuum deposition apparatus as a cathode together with at least one anode of a film-forming metal and at least one anode of a non-film-forming

conductor and coating at least part of the base with the said mixed-crystal material by sputtering.

40. A process for making an electrode for use in electrolytic processes substantially as herein described with reference to any one of the Examples given.

41. An electrode manufactured by the

process as claimed in any one of claims 9 to 40.

42. An electrolytic process using an electrode as claimed in any one of claims 1 to 8 or claim 41.

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COMPLETE SPECIFICATION

1 SHEET

*This drawing is a reproduction of
the Original on a reduced scale*

FIG- 1

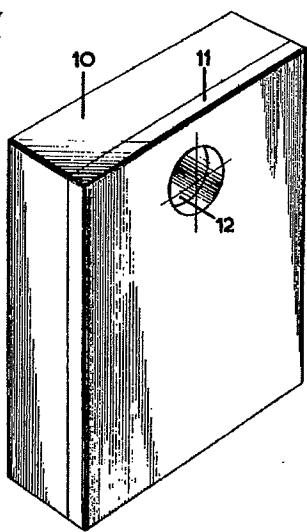


FIG- 2

